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Fuzzy-adaptive control method for off-road vehicle guidance system

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ABSTRACT

Navigation decision-making for off-road vehicle is very important in precision agriculture. Since the operating environment of the agricultural vehicles have the diversity and complexity, it is necessary for the navigation decision-making method to have self-adaptability and robustness. Simulation can make accurate predictions for the dynamic behavior of the vehicle, and provide analytical basis for the design of vehicle navigation systems. In this study, a new type of three-dimensional vehicle guidance simulation system was developed and a vehicle model was created based on MRDS. The fuzzy-adaptive control method was designed to solve the problem of overshoot. The results of simulation and real navigation experiment showed that the developed system could achieve the simulation of vehicle navigation and control successfully and provide the help to the design of the real navigation systems, and the designed fuzzy-adaptive control method could effectively weaken the control process overshoot.

1. Introduction

Vehicle intelligent guidance, as a multi-disciplinary integration technology, is a complex area of artificial intelligence. Automatic navigation of agricultural vehicles is one of the hotspot in precision agriculture.

Simulation can make accurate predictions to the dynamic behavior of the vehicle and provide analytical basis for the design of vehicle navigation system. Currently, simulation model research normally focuses on the mechanical structure and dynamics model, less research on the sensor function and control methods, and it is difficult to solve concurrent execution and event-driven issue problems in real-world [1,2]. MRDS (Microsoft Robotics Development Studio) is a service-oriented visual robot programming kit, developed by Microsoft Corporation. MRDS includes a.NET-based, service-oriented runtime, which can reduce burden of dealing with multi-threaded tasks for developers, and improve the system stability [3]. In some developed countries, MRDS began to be applied to education and the development of commercial products. Simon Blackmore combined MRDS with Google Earth, developed an agricultural Robot simulation software SAFAR (Software Architecture for Agricultural Robots), in order to provide a platform and method for the design of agricultural Robot effectively ([4]). A new security robot simulation system was developed based on MRDS, used to plan security robot behavior and motion in a credible physics-based environment [5].

Navigation decision-making control method is usually based on three control models: linear control model, optimal control model, and fuzzy control model. Since the operating environment of the agricultural vehicles has the diversity and complexity, the process of automatic navigation may be affected by the modeling errors, parameter perturbations and external disturbances, and other uncertainties [6]. It is required for the navigation decision-making method to have self-adaptability and robustness.

This study aims to develop a 3D vehicle intelligent guidance simulation platform. By using the platform, the navigation decision-making control algorithms will be studied, and then the real vehicle comparison experiment will be conducted to test the control methods.

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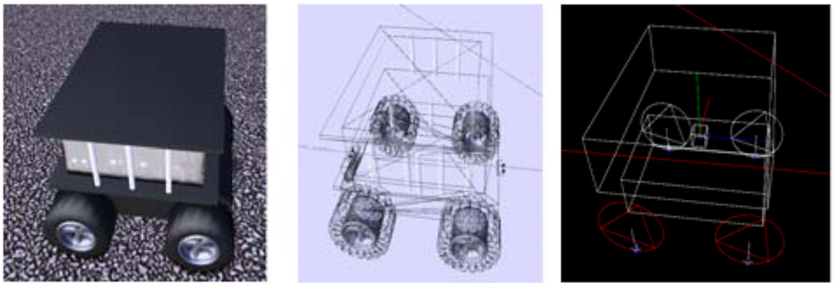


Fig. 1. Display of hybrid model.

2. Material and methods

2.1. Development of the simulation platform

MRDS is a Windows-based visual robot programming kit and offers a service-oriented runtimes. The structure of MRDS has three lays [7]. The bottom lay is the simulation engine based on the AGEIA physX engine along with Microsoft XNA Framework and DirectX 9 runtime. The middle lay includes Concurrency and Coordination Runtime (CCR) and Decentralized Software Services (DSS), which implement multi-threaded asynchronous processing and interact with simulation services in real-time. The top lay includes VSE (Visual Simulation Environment) and VPL (Visual Programming Language).

The developed simulation system had several basic service components, including the simulation environment and model service, model-driven service, interactive service, and simulation engine service. Different services communicated with each other through message. They all ran on one DSS node, which provided loading environment for services.

(1) *Structure and physical model of vehicle*

The complex physical structure model requires a large number of kinematical and dynamic calculations in the simulation process, but it will decrease the real-time capability of the simulation system [8]. In this system, the simple physical structure (Box, capsule, etc.) included in MRDS kit and three-dimensional vector types have been used to create complex mechanical structure. 3D modeling tools were used to generate the geometry of the model. As shown in Fig. 1. The vehicle model of the system included body, wheels, and several sensors. The body also included two properties, position and current heading. Those could be read in real-time in order to simulate the function of GPS and electronic compass.

(2) *The Model-driven service*

The model-driven service was connected with the vehicle model and simulation engine. The main role of the service was to achieve subscribed messages and then process between them [9]. Furthermore, the model-driven service provided a four-wheel simulation drive method, and a steer-turning method of the front wheels. The interleave arbiter provided by CCR runtime, was used in the model-driven service, in order to subscribe messages from model to operation handles.

(3) *Customer interface*

Windows form as custom interface was used to interact with services in the system. The functions of the custom interface included selection of navigation method, test of model-driver, display parameters of model, and start and stop of simulation.

2.2. Development of the navigation platform

LOVOL FT704 tractor was used as a navigation platform, as shown in Fig. 2. DGPS receiver, AHRS, angle sensors and two controllers were installed in the tractor. DGPS receiver and AHARS are used to provide position and attitude of the tractor [10]. Two controllers, one is used to data collection and navigation decision making, the other is used to specific control tasks.

2.3. Navigation control method

(1) *Principle of straight-line navigation*

The main tasks of the navigation control were to determine the location of the vehicle and the position between the pre-set routes based on the results of positioning, make the right steering angle combined with the movement of vehicles, and correct the path tracking error. The principle of the straight line navigation is shown in Fig. 3. Using a pre-set straight as the navigation path, where (x, y), (X_0, Y_0), (X_1, Y_1) are the vehicle current position, scheduled to start and end positions. The distance between the pre-set path and the vehicle was called the lateral deviation E, the angle between vehicle steering angle and the pre-set path was called the heading error ψ. Through E and ψ, the expected front wheel corner could be calculated, and sent to the navigation controller. Good navigation control method could control the process with good stability, speed and accuracy.

(2) *Fuzzy-adaptive control method*

Fig. 2. Experimental platform.

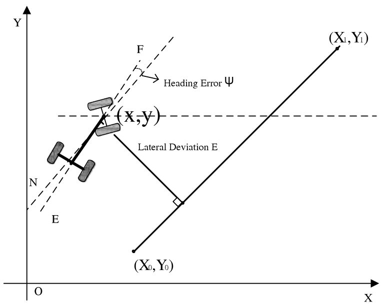


Fig. 3. Principle of straight-line navigation.

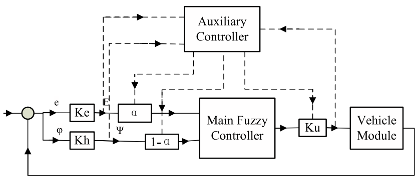


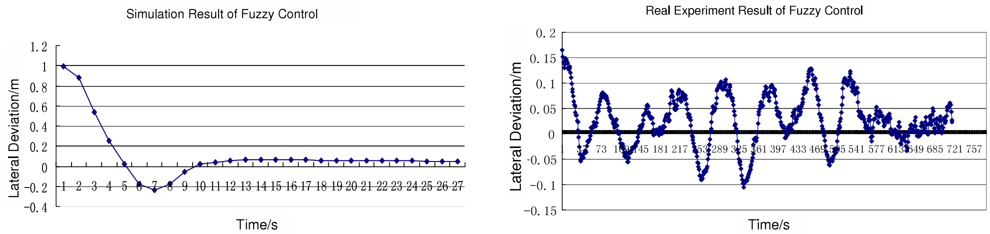
Fig. 4. Block diagram of fuzzy adaptive control method.

For more complex process, using a fixed set of parameters was difficult to achieve the desired control effect. The scale factor $K_u$of the fuzzy control had a greater impact on control performance, and the fixed adjustment factor could not meet the control requirements of the various stages of the process. Hence, an online adaptive fuzzy control method was developed. Using the fuzzy lateral deviation E and the heading error ψ as the input, an auxiliary controller was designed to K_u adjusting and the U calculating on line. The Control rules and the system block diagram were shown in Fig. 4 and Eqs. (1)–(3).

$$U = -\langle \alpha E + (1-\alpha)\Psi \rangle, \quad \alpha \in (0, 1) \tag{1}$$

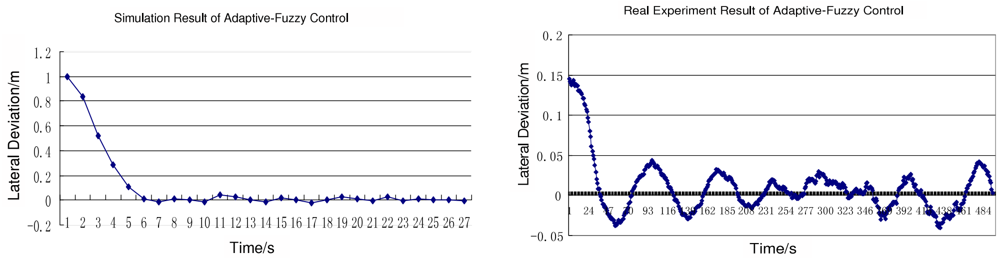
$$\alpha = \frac{1}{E_{\max}} * 0.5|E| + 0.3 \tag{2}$$

$$K_u(n+1) = K_u(n) * 2^{\frac{|E+\Psi|}{E_{\max}+\Psi_{\max}}}, \qquad K_u(0) = 4. \tag{3}$$



(a) Simulation result. (b) Real experiment result.

Fig. 5. The result of fuzzy control method in straight line.



(a) Simulation result. (b) Real experiment result.

Fig. 6. The result of fuzzy-adaptive control method in straight line.

3. Results and discussion

In order to verify the straight navigation control methods and the reliability of the simulation platform, the ordinary fuzzy control method and the adaptive fuzzy control method were tested on the tractor in order to check the performance of the control methods.

In the experiment, the lateral deviation of the basic domain was [−30 cm, 30 cm], quantization factor $Kxte = 6/30 = 0.2$; heading error of the basic domain was [−24, 24], quantization factor $Kh = 6/24 = 0.25$. In the ordinary fuzzy control method, the scale factor K_u was 4, the adjustment factor a was 0.6. In the simulation platform, the starting point coordinates of the pre-set path was (1, 0) and the end point coordinates was (2, −10). The vehicle starting position was (0, 0), the lateral deviation was about 1 m, heading error was 0, the speed was 0.4 m/s. In the real tractor, through the PLC controller for steering control, the speed was 2 m/s. The results are shown in Figs. 5 and 6.

From the experiment results, it was found that the fuzzy-adaptive control method could effectively weaken the control process overshoot, and the control accuracy was better than the ordinary fuzzy control method in steady-state. Since the simulation environment was the ideal scenario, the deviation of the vehicle was the smaller than the test result of the actual navigation. For the further research, the complex simulation environment should be created, in order to further verify the control performance.

4. Conclusions

In this study, a simulation platform based on MRDS for vehicle guidance was developed, and the navigation simulation control services were built. A fuzzy-adaptive control method was designed and the performance was checked in simulation and real navigation platform. The Simulation and real experimental results showed that the software platform could effectively simulate the process of the vehicle navigation and provide the design basis for actual navigation system. The fuzzy-adaptive control method could effectively reduce the overshoot compared with traditional control methods.

Acknowledgments

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